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Inter-comparison of Terra and Aqua MODIS

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Nearly identical copies of the Moderate Resolution Imaging Spectroradiometer (MODIS) have been operating on-board the NASA's Earth Observing System (EOS) Terra and Aqua satellites since their launches in December 1999 and May 2002 respectively. Each MODIS has 20 reflective solar bands (RSB) with center wavelengths from 0.41 to 2.1μm and 16 thermal emissive bands (TEB) from 3.7 to 14.4μm. The absolute radiometric calibration accuracy requirements (1sigma) at the top of atmosphere (TOA) typical scene radiances are ±2% for the RSB reflectance factors and ±5% for the RSB radiance products. With a few exceptions, the TEB radiance calibration requirements are ±1%. In order to achieve and maintain its calibration accuracy, each MODIS is equipped with a set of on-board calibrators (OBCs), including a solar diffuser (SD) and a solar diffuser stability monitor (SDSM) for the RSB calibrations and a blackbody (BB) for the TEB calibrations[1]. The SDSM is used to track the SD reflectance changes on-orbit. In addition, lunar observations have been extensively used by both Terra and Aqua MODIS to support their on-orbit calibration and characterization[2].

In principle, both Terra and Aqua MODIS should have the same calibration scale since their on-board calibrators were calibrated pre-launch against the same ground sources. For example, the SD bi-directional reflectance was characterized in a comparison mode using a reference sample traceable to NIST reflectance standard and the on-board BB was characterized using a laboratory blackbody calibration source (BCS) with high emissivity (0.9995) over the spectral range of the thermal emissive bands[3,4]. This paper describes MODIS lunar calibration methodology and its applications to the inter-comparison of Terra and Aqua MODIS RSB in the visible (VIS) and near-infrared (NIR) spectral regions and the inter-comparison of Terra and Aqua MODIS TEB on-orbit calibration consistency using closely matched thermal infrared (TIR) channels on the Advanced Very High Resolution Radiometer (AVHRR) at 11μm and 12μm. These two channels are primarily used for retrieving sea-surface temperature (SST) and land surface temperature (LST) and, therefore, have higher calibration accuracy requirements.

Inter-comparison of Terra and Aqua MODIS RSB calibration using the Moon

One of the MODIS on-orbit operational activities is to plan and perform lunar observations. The primary objective of MODIS lunar observations is to support the RSB calibration by tracking their on-orbit radiometric stability. The Moon is a very stable calibration source because of the intrinsic stability of its surface reflectance properties[5,6]. In order to reduce the uncertainty in the corrections, due to lunar viewing geometry differences, the lunar observations for both instruments are carefully scheduled to occur at nearly the same phase angle (55-56˚) via spacecraft roll maneuvers with Terra viewing a waning Moon while Aqua views a waxing Moon.

Each MODIS views the Moon through its space view (SV) port, approximately 9 times a year. Depending on the observing time and viewing geometry, the sensor can view the Moon over multiple scans. For a given spectral band, we compute a quantity called the integrated lunar irradiance that depends on the calibration coefficients, lunar viewing geometry factors (the Sun-Moon-MODIS phase angle, the lunar libration angles, and the Sun-Moon and the Moon-MODIS distances), and the over-sampling factor when multi-scan observations are used.

Figure 1 presents an example of a time series of the measured lunar irradiance for Terra MODIS band 1 with a center wavelength at 647nm. The starting time is chosen to match the Aqua MODIS time series. The large annual oscillation is primarily due to the variations in viewing geometry of the lunar observations. For comparison purposes, the modeled lunar irradiance under the same viewing condition is also included in this plot. Clearly the modeled results have trending similar to that of the measurements. The modeling results are computed using Robotic Lunar Observatory (ROLO) program from the U.S. Geological Survey (USGS)[7]. Notice that there is a near-constant scaling factor between the measurements and modeling results that should include the errors in both the modeling and measurements. As one would expect, the difference is spectral band (wavelength) dependent. Similar time series or trending results for the Aqua MODIS bands 1 are shown in Figure 2. Because of the viewing geometry differences between the Terra and Aqua MODIS lunar observations, the overall shapes of their time series (trending) are not exactly the same. Like Terra MODIS, an approximately constant and spectral band dependent scaling factor between the modeling and measurements also exists in the Aqua MODIS lunar irradiance trending.

If this scaling factor for a given band is the same for both Terra and Aqua MODIS, then their on-orbit calibration is considered to be consistent. For MODIS band 1, the calibration difference between Terra and Aqua is about 1±0.5%. This inter-comparison approach has been applied to all MODIS reflective solar bands that do not saturate during lunar observations. Current results from Terra and Aqua MODIS lunar observations show that the overall calibration difference between the two sensors' reflective solar bands is less than ±1%. We have also applied this approach of using the Moon for calibration inter-comparison of MODIS with other sensors, such as the MISR on the Terra spacecraft and the SeaWiFS[8].